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19. Abstract (Cont'd)

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EVALUATION OF THREE COMMERCIAL MICROCLIMATE COOLING SYSTEMS

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ABSTRACT

Three commercially available microclimate cooling systems were evaluated for their ability to reduce heat stress in men exercising in a hot environment while wearing high insulative, low permeability clothing. Five male volunteers performed three 180 minute experiments (three repeats of 10 min rest, 50 min walking at 440 watts) in a 38°C Ta; 12°C Tdp environment. The cooling systems were : 1) ILC Dover Model 19 Coolvest (ILC), mean inlet temperature 5.0°C; 2) LSSI Coolhead (LSSI), mean inlet temperature 14.5°C; and 3) Thermacor Cooling Vest (THERM), mean inlet temperature 28.3°C. Endurance time (ET), heart rate (HR), rectal temperature (T_{re}), mean skin temperature (T_{sk}), sweating rate (SR), rated perceived exertion (RPE) and thermal sensation (TS) were measured. Predicted ET based on no cooling was 101 min. ET was greater ($p<0.01$) with ILC (178 min) than THERM (131 min) which was greater ($p<0.01$) than LSSI (83 min). The subjects self terminated on all LSSI tests because of headaches. Statistical analyses were performed on data collected at 60 minutes to have values on all subjects. There were no differences in HR, T_{re}, SR or TS values among the cooling vests. The subjects' T_{sk} was lower ($p<0.05$) for the LSSI than THERM; and RPE values were higher ($p<0.05$) for LSSI than the other two vests. These data suggest an improved physiological response to exercise heat stress with all three commercial systems with the greatest benefit in performance time provided by the ILC cooling system.

Index terms: liquid cooling; heat stress; exercise; thermoregulation

INTRODUCTION

Both civilian and military personnel in certain situations have to work in contaminated environments. For example, there are requirements to clean up toxic waste, fight fires with noxious fumes, and face possible exposure to chemical weapons. Any of these situations require wearing permeable or semi-permeable protective clothing to prevent environmental contamination. While this clothing is reliable for protecting the wearer from the external environment, it also creates a microclimate which does not favor heat dissipation (21). The lack of permeability greatly reduces the potential for evaporative and convective cooling, with the result that metabolic heat as well as external heat sources serve to drive up the wearers body temperature(5,6,13). Strenuous physical exercise performed with high skin and core temperatures will lead to reduced performance and possible syncope (15). To work for any extended period in this clothing the wearer must be provided with a cooling system to reduce or eliminate the body heat storage (5,6,13).

Numerous microclimate cooling systems, designed to cool the area between the body and clothing layer, have been developed and tested over the years(7,9,10,13,16,17,19,20,22,23). Many of these systems have been developed by the military to meet their unique requirements(21). However, commercially developed microclimate cooling systems have been manufactured to meet the needs of the private sector. Periodically, the military will evaluate commercially available systems to determine if off the shelf items can meet its unique needs (3). This study evaluated the physiological responses of humans exposed to an exercise-heat stress when equipped with each of three commercially available microclimate cooling systems.

MATERIALS AND METHODS

Five healthy males volunteered after being informed verbally and in writing of the purpose and procedures of the research. Each expressed understanding by signing a statement of informed consent. All subjects were medically screened prior to involvement in the study. Anthropometric measurements of height, weight, and per cent body fat estimated by skinfold thickness at four sites (4) were obtained. The study was conducted in July in Natick, Massachusetts, and while it was assumed that subjects would be naturally heat acclimated, they did participate in a four day heat acclimation program prior to the beginning of experimental tests. Each acclimation day the subjects walked on a level treadmill at 1.34 $m \cdot sec^{-1}$ for 180 minutes (three repeats of 10 minutes rest, 50 minutes exercise) in a 38°C T_{db}, 11.7°C T_{dp}, 1.13 $m \cdot sec^{-1}$ wind speed environment. During heat acclimation the subjects wore shorts and tennis shoes.

Following heat acclimation all subjects completed three heat stress tests with identical exercise and environmental conditions as the heat acclimation program. In all heat stress tests, subjects wore a T-shirt, one of three cooling vests, combat vehicle crewman (CVC) fragmentation protective vest, CVC Nomex coveralls, chemical/biological overgarment (pants and jacket), M-17 gas mask, butyl rubber hood, CB butyl rubber gloves with cotton liners and CB Butyl rubber overboots. Helmets were not worn. The filter elements were removed from the masks to facilitate breathing Estimated insulative and evaporative values for the complete uniforms were clo=2.75 and i_m=0.30 respectively (C. Levell unpublished data). The subjects attempted experiments on three separate days during which they wore either ILC Dover Model 19 Cool Vest (ILC), the Life Support Systems, Inc. Cool

Head (LSSI) or the Thermacor Technology, Inc. Thermacor vest (THERM). The order of cooling system presentation was systematically varied for each subject.

The ILC vest consisted of two urethane-coated nylon bladders,worn as panels on the chest and back and providing a potential cooling surface area of 0.17 m^2. The bladders were heat sealed in spots to provide flow channels within each panel. One panel was integrated with a pouch containing a pump and battery holder in addition to a bag which was filled with 1.64 kg of ice cubes and 1.5 L of water to circulate through the panels. This pouch was worn on the chest by the subjects to facilitate ice refills during the heat stress tests. The water was circulated through the system at an average rate of 2.65 $l \bullet min^{-1}$. Mean inlet temperature of the water was 5.0°C. Testing procedure was that water evolved from melting ice was drained every hour and a new 1.64 kg of ice was placed in the pouch. The battery was replaced every two hours. The ILC vest could provided a theoretical cooling of 152 W per refill if all the ice evolved to water in 60 minutes. Total weight of the system as operated was 7.4 kg.

The LSSI vest was also constructed of urethane coated nylon with heat sealed channels for the coolant to flow through. The panels covered chest and back and were connected in series to a cooling cap. The total cooling surface area was 0.23 m^2. In the LSSI vest the batteries and coolant reservoir were mounted on a back harness separate from the cooling vest. Cooling was provided by a propylene glycol mixture circulated through the vest and cap and past two 1.0 kg ice cannisters at an average flow rate of $4 \bullet 10^{-1}$ $L \bullet min^{-1}$. Mean inlet temperature of the coolant was 14.5°C. Testing procedure was that ice cannisters were replaced every 45 minutes. The LSSI vest provided a theoretical cooling of 233 W per set of two ice cannisters. Total weight of the system was 7.6 kg.

The THERM vest utilized the heat of vaporization of dichlorotetrafluoroethane (R114) to cool the wearer of a vest covering the chest

and back. Pressurized R114 was delivered to 16 hexagonal packets located throughout the vest providing a total cooling surface area of 0.18 m^2. Coolant was provided by a pressurized cannister containing 1.34 kg of R114, and belted around the waist separate from the vest. Flow to the vest was controlled by six solenoid valves operated by a small box powered by a 9-volt transistor battery and worn in the front of the vest. Mean evaporative temperature measured at two packets was 28.3°C. The cannisters were changed every 20 minutes during the heat stress tests. The THERM vest could theoretically provide 101 W of cooling to the wearer. Total weight of the system as operated was 4.8 kg.

During all heat exposures subjects inserted a rectal thermister 10 cm beyond the anal sphincter to measure core temperature (T_{re}). Additionally, in all heat exposures heart rate (HR) was determined by electrocardiograms obtained from chest electrodes (CM5 placement) telemetered for display on an oscilloscope cardiotachometer unit. On the heat stress test days, subjects additionally were fitted with a three site (arm, chest, leg) thermocouple harness to obtain skin temperature values for calculating mean weighted skin temperatures (T_{sk}) (2). Additional thermocouples were placed within the flow loops of the ILC and LSSI systems and at two of the packets of the THERM system to calculate actual cooling provided to the wearers.

The cooling systems were switched on just prior to the subjects entering the environmental chamber for the initial rest period of each heat stress test. Subjects were required to break the integrity of their gas masks to allow breathing into a mouthpiece for the collection of expired gases during the heat stress tests. Expired gases were collected in 100 liter Douglas bags and were analyzed for ventilatory volume, and per cent carbon dioxide and oxygen to determine the metabolic rate. During the tests all subjects were allowed to drink water *ad libitum* through a plastic drinking straw inserted under the gas mask. All water

intake was measured and whole body sweating rate (SR) was calculated from nude weight changes corrected for water intake. Subjects were also asked for subjective ratings of perceived exertion (1) and thermal sensation (23).

Analyses of variance for repeated measures were used to analyze physiological responses at the completion of 60 minutes of exercise as well as for analyses of total exposure time and SR for each test day. A multivariate regression analysis was used to compare the subjects change in T_{re} among the three cooling systems. All analyses were performed only on data obtained during the first 60 minutes as it was the final time with complete data sets for all five subjects. Tukey's test of critical difference was used for post-hoc tests. All differences are reported at $p<0.05$.

RESULTS

The mean (± standard deviation) subject age was 23 (±6) years, height, 175 (±4) cm, weight, 66 (±12) kg, Dubois body surface area (A_D), 1.80 (±0.16) m^2 and body fat, 14.6 (±6.7) per cent. The subjects metabolic rate during exercise was 440 (±68) watts and found to be consistent throughout the three heat stress tests. The mean, actual cooling rate (Figure 1) provided by the vests was calculated to be 244 (±68) W for ILC, 222 (±29) W for LSSI and 108 (±17) W for THERM, with THERM values being less ($p<0.05$)than the other two systems. The predicted exposure time while wearing MOPP 4 with no microclimate cooling was 101 minutes (12). The measured exposure time (Figure 2) for subjects with ILC at 178 (±4) minutes was greater ($p<0.05$) than with both other vests, and exposure time for subjects with THERM at 131 (±47) minutes was greater ($p<0.05$) than with LSSI at 83 (±18) minutes.

FIGURE 1 AND FIGURE 2 HERE

Table 1 presents physiological responses obtained with the three cooling systems at 60 minutes of exposure to the heat stress tests. Although there were no significant differences, mean values in three of the four indices of heat stress were highest with the THERM system, which was statistically shown to provide the least cooling. Figure 3 shows the regression lines for core temperature responses when wearing the three cooling systems. There were no significant differences in the intercept or slope of lines representing the change in T_{re} over time when exercising in the three systems. However, these values were also plotted against a prediction line of T_{re} changes while wearing MOPP 4 at equivalent exercise with no cooling (12). The predicted T_{re} values for no cooling were higher than the mean values observed with any of the microclimate cooling systems. Mean average SR values and HR values also showed no significant difference among the three cooling systems (Table 1). T_{sk} values did show a difference between systems with LSSI (32.7°C) being less($p<0.05$) than THERM (36.2°C) at the 60 minute value (Table 1).

TABLE 1 AND FIGURE 3 HERE

Subjective evaluations of exertion (Table 2) did show significant differences in responses taken at minutes 25, 40 and 55 of heat exposure. The subjects wearing LSSI responded with a greater ($p<0.05$) perceived exertion than with both

of the other two cooling systems at each time period. However, during no time period did the subjects perceive any difference in thermal sensations among the three vests. Finally, beginning shortly after the start of exercise, all subjects reported a severe and worsening headache when wearing the LSSI system .

TABLE 2 HERE

DISCUSSION

The insulation and low permeability provided by standard military MOPP 4 level protective clothing exemplify the conditions which would be experienced by individuals required to work in a toxic environment. The three cooling systems tested with the MOPP 4 configuration are likewise representative of state of the art commercially available equipment. Examination of the core temperature regression lines for subjects while wearing all three cooling systems shows lower T_{re} values compared to predicted no cooling values. This is not unexpected given the results of previous studies on the effectiveness of liquid microclimate cooling systems (7,10,19,23). However, there were clear differences in the performance capabilities of the three systems.

The subjects had the longest exposure time in the exercise heat stress tests while wearing the ILC system. While there were no significant differences among the physiological responses to the systems, there was a trend for the physiological responses (Table 1) and thermal sensations (Table 2) to be lowest with the ILC system . The simplicity of the ILC system, pumping water past melting ice as a

heat sink, made it very effective for short term use. The system does have inadequacies for sustained operations. At the metabolic rate used during these experiments, the ice in the pouches was entirely melted before the one hour resupply. It is not unusual for soldiers to work at metabolic rates of 400-550 watts for extended periods of time (8). The efficiency of the system would be expected to decline with increasing environmental or metabolic demands necessitating both a loss of work time, and a large store of ice for resupply. In addition, the necessity to place the system entirely inside the protective clothing would require leaving the contaminated work area prior to replenishing the cooling supply. This is a significant drawback for the military user in a chemical warfare battlefield, who can neither break the integrity of his protective uniform nor has the ability to leave his environment for resupply.

The relatively short mean exposure time observed in the subjects wearing the LSSI system was unexpected, in that the LSSI system and ILC system had calculated cooling rates which were nearly identical. Examination of physiological responses to the heat stress tests also indicated no significant differences among the LSSI and either of the other systems. However, ratings of perceived exertion were significantly higher for the subjects while wearing the LSSI relative to the two systems with no head cooling (Table 2). While wearing the LSSI system all subjects suffered headaches which were debilitating to the extent that they all requested early removal from the treadmill. This problem had not been noted in previous studies involving use of head cooling (11,17,18). In those previous studies individual control of either flow rate (11) or coolant temperature (11,17,18) was provided during exercise. In the current study design, flow rate and temperature were preset and started prior to the subjects beginning a 10 minute rest in the heat. Therefore, the headache problem might be alleviated if individuals were

allowed more control over the temperature or flow rate of the coolant reaching their head. A secondary problem with the LSSI system is the low flow rates which allow air bubbles to easily block the coolant flow reducing the ability to reduce heat storage. While the controls and heat sink of the LSSI are outside the protective garments for easy accessibility, blocked cooling channels require leaving the contaminated area to open the protective equipment and correct the problem. The necessity of changing cooling cartridges every 45 minutes also presents a logistics problem for sustained use.

The THERM system while the lightest of the three systems also provided significantly less cooling than the other two, and would not be expected to provide cooling sufficient to markedly reduce heat storage if an individual was required to work at a higher metabolic level. This reduced cooling was indicated by the tendency for increased physiological responses in the subjects. Further, the necessity of changing coolant tanks every 20 minutes creates a major logistics problem for sustained operations. However, because the THERM system cools by the vaporization of the fluourocarbon it will provide a constant rate of cooling for the life of a coolant tank,and not be affected by melting ice as in the other systems. Larger tanks would last longer , but would be heavy and awkward offsetting the one advantage of the system.

In addition to the individual logistics problems cited for each cooling system, they all have two problems in common with many other self-contained microclimate cooling systems (3,1[illegible],16,19,21,23). No tested system was capable of providing sufficient cooling to prevent heat storage in subjects working at a moderate energy expenditure (440 W) in a hot-dry environment. Typically, self paced work for an average soldier would be expected to elicit 450-550 W (8). At best the ILC and

LSSI systems can only provide one half of the necessary cooling, and only for a limited period of time. A further problem resulting from the low cooling capacity of each system was the mean sweating rate of approximately one liter per hour for the subjects. Almost none of this sweat was evaporated inside the vapor exchange resistant protective clothing. The subjects were dehydrating without the advantage of evaporative cooling. This dehydration is not easily counteracted because of the difficulty of drinking inside protective clothing. Dehydration combined with warm skin and exercise can easily result in syncope and heat exhaustion (15).

In conclusion, there are commercially available microclimate cooling systems to help reduce some heat storage for individuals working in a toxic environment. These systems may have some application to civilian problems requiring brief exposure to toxic agents or in situations where the worker can leave the contaminated site for resupply. However, they do not appear to have much military application. Overall physiological and perceptual results from these experiments indicate that the ILC system provides the best support for the individual working in a hot environment with protective clothing. However, the systems tested can provide cooling sufficient to offset only light to moderate work, and all necessitate a large quantity of supplies for sustained operations.

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The views, opinions, and/or findings contained in this report are those of the authors and should not be construed as an official Department of the Army position, policy or decision unless so designated by other official documentation.

Human subjects participated in these studies after giving their free and informed voluntary consent. Investigators adhered to AR 70-25 and USAMRDC Regulation 25 on Use of Volunteers in Research.

Reference to specific equipment, trade names and manufacturers is for identification purposes only and does not imply endorsement by the U.S. Army or the U.S. Department of Defense.

REFERENCES

1. Borg G. Perceived exertion as an indicator of somatic stress. Scand. J. Rehab. Med. 2-3:92-98, 1970.

2. Burton AC. Human calorimetry II. The average temperature of the tissues of the body. J. Nutr. 9:261-80, 1935.

3. Cosomini H,Cohen J, DeCristofano B, Goff R, Iacono V, Kupcinskas M, Tassinari T, Pimental NA, Cadarette BS, Holden WL, Levine L, Pandolf KB, Sawka MN. Determination of the feasibility of two commercial portable microclimate cooling systems for military use. Technical Report No. TR-85/033L. U.S. Army Research, Development and Engineering Center, Natick, MA 01760-5007, 1985.

4. Durnin JVGA, Womersley J. Body fat assessed from total body density and its estimation from skinfold thickness: measurements on 481 men and women aged from 16 to 72 years. Br. J. Nutr. 32:77-97, 1974.

5. Goldman RF. Tolerance time for work in the heat when wearing CBR protective clothing. Milit. Med. 128:776-86, 1963.

6. Henane R, Bittel J, Viret R, Morino S. Thermal strain resulting from protective clothing of an armored vehicle crew in warm conditions. Aviat. Space Environ. Med. 50:599-603, 1979.

7. Kaufman WC, Pittman JC. A simple liquid transport cooling system for aircrew members. Aerospace Med. 37:1239-43, 1966.

8. Levine L, Evans WJ, Winsmann FR, Pandolf KB. Prolonged self-paced hard physical exercise comparing trained and untrained men. Ergonomics. 25:393-400, 1982.

9. Muza SR, Pimental NA, Cosimini HM, Sawka MN. Portable, ambient air microclimate cooling in simulated desert and tropic conditions. Aviat. Space Environ. Med. 59:553-58, 1988.

10. Nunneley SA. Water-cooled garments: a review. Space Life Sci. 2:335-60, 1970.

11. Nunneley SA, Troutman Jr. SJ, Webb P. Head cooling in heat work and heat stress. Aerospace Med. 42:64-8, 1971.

12. Pandolf KB, Stroschein LA, Drolet LL, Gonzalez RR, Sawka MN. Prediction modeling of physiological responses and human performance in the heat. Comput Biol Med, 16:310-29, 1986.

13. Pimental NA, Cosimini HM, Sawka MN, Wenger CB. Effectiveness of an air-cooled vest using selected air temperature and humidity combinations. Aviat. Space Environ. Med. 58:119-24, 1987.

14. Sawka MN. Body fluid responses and hypohydration during exercise-heat stress. In: Pandolf KB, Sawka MN, Gonzalez RR, eds. Human performance

physiology and environmental medicine at terrestrial extremes. Indianapolis:Benchmark Press, 1988:227-66.

15. Sawka MN, Wenger CB. Physiological responses to acute exercise-heat stress. In: Pandolf KB, Sawka MN, Gonzalez RR, eds. Human performance physiology and environmental medicine at terrestrial extremes. Indianapolis:Benchmark Press, 1988:97-151.

16. Shapiro Y, Pandolf KB, Sawka MN, Toner MM, Winsman FR, Goldman RF. Auxiliary cooling: comparison of air-cooled versus water-cooled vest in hot-dry and hot-wet environments. Aviat. Space Environ. Med. 53:13-17, 1982.

17. Shitzer A, Chato JC, Hertig BA. Thermal protective garment using independent regional control of coolant temperature. Aerospace Med. 44:49-59, 1973.

18. Shvartz E. Effect of a cooling hood on physiological responses to work in a hot environment. J. Appl. Physiol. 29:36-9, 1970.

19. Shvartz E. Efficiency and effectiveness of different water cooled suits - a review. Aerospace Med. 43:488-91, 1972.

20. Shvartz E, Aldiem M, Ben Mordechai J, Shapiro Y. Objective approach to a design of a whole-body, water-cooled suit. Aerospace Med. 45:711-15, 1974.

21. Speckman KL, Allan AE, Sawka MN, Young AJ, Muza SR, Pandolf KB. A review: microclimate cooling of protective overgarments in the heat.

Technical Report No. T9-88. U.S. Army Research Institute of Environmental Medicine, Natick, MA 01760-5007, 1988.

22. Webb P. Thermoregulation in actively cooled working man. In: Physiological and Behavioral Temperature Regulation. J Hardy, AP Gagge and JAJ Stolwijk, eds. Springfield, IL, CC Thomas, 1970, p 757-74.

23. Young AJ, Sawka MN, Epstein Y, DeCristofano B, Pandolf KB. Cooling different body surfaces during upper and lower body exercise. J. Appl. Physiol. 63:1218-23, 1987.

TABLE 1. MEAN (±SD) VALUES FOR RECTAL TEMPERATURE (Tre), MEAN WEIGHTED SKIN TEMPERATURE (Tsk), WHOLE BODY SWEATING RATE (SR), AND HEART RATE (HR) DURING THE 60 MIN OF EXERCISE IN THE HEAT.

	Tre °C	ΔTre °C	Tsk °C	SR $g \cdot min^{-1}$	HR $b \cdot min^{-1}$
ILC	37.7 (0.3)	0.79 (0.2)	37.5 (1.3)	15.8 (3.6)	138 (15)
LSSI	37.9 (0.4)	0.99 (0.3)	32.7* (1.9)	20.0 (7.3)	153 (21)
THERM	38.1 (0.4)	1.16 (0.5)	36.2 (0.5)	20.6 (5.7)	145 (9)

* LESS THAN THERM ($p<0.05$)

TABLE 2. RATINGS OF PERCEIVED EXERTION (RPE) AND THERMAL SENSATION (TS) TAKEN AT MINUTES 25, 40, AND 55 OF HEAT EXPOSURE.

	RPE			TS		
	25	40	55	25	40	55
ILC	12.8 (0.8)	13.4 (1.3)	14.0 (1.4)	4.4 (1.9)	4.6 (2.1)	5.3 (1.1)
LSSI	14.4* (1.8)	15.4* (1.8)	15.4* (1.8)	5.5 (0.4)	6.1 (0.7)	6.0 (0.4)
THERM	13.0 (1.2)	13.2 (1.3)	13.8 (1.5)	5.3 (0.4)	5.5 (0.4)	5.9 (0.7)

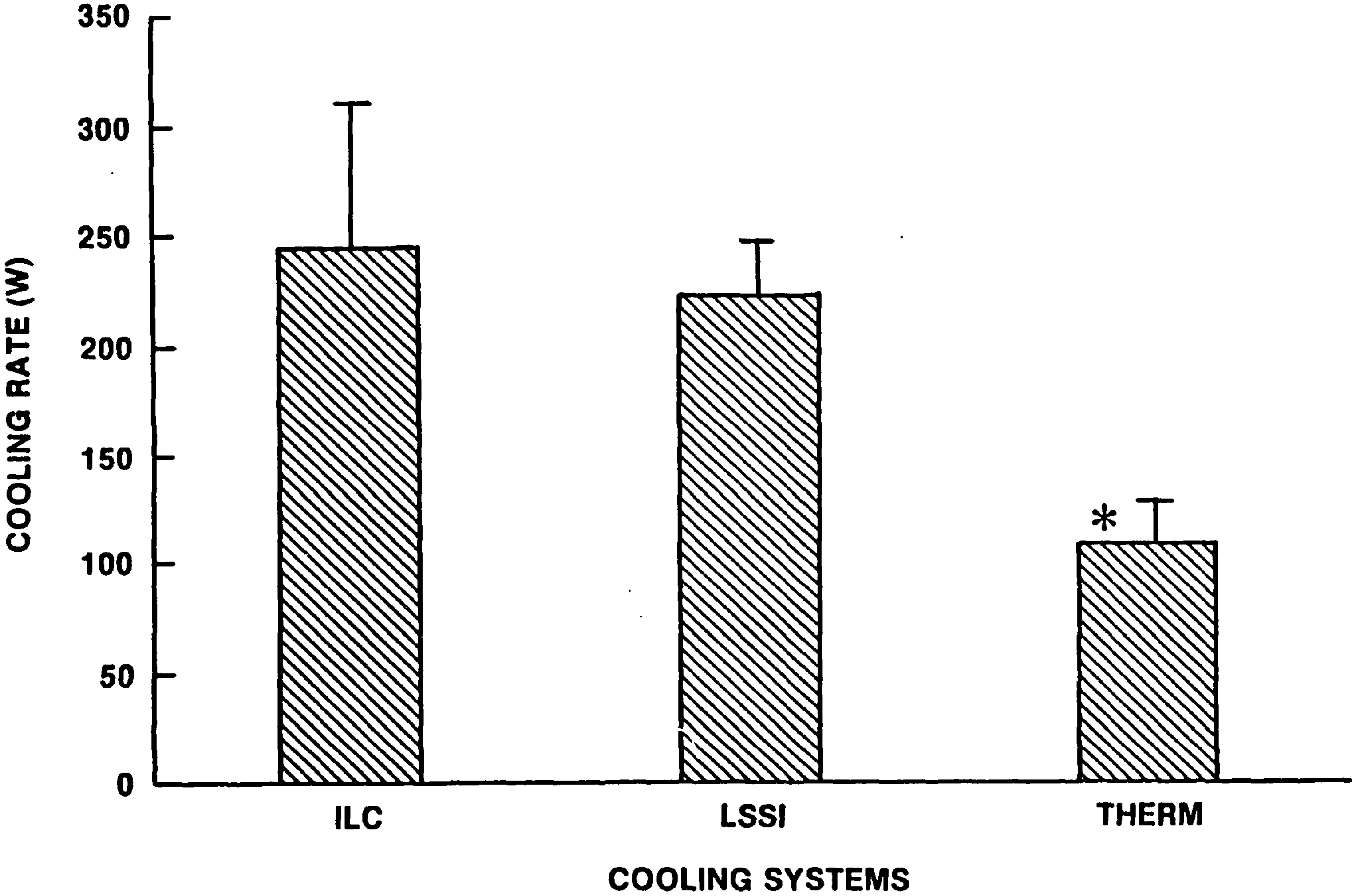
*GREATER THAN ILC AND THERM ($p<0.05$)

FIGURE LEGENDS

Fig. 1. Calculated cooling rates ($\bar{X}$, S.D.) provided by the three microclimate systems.

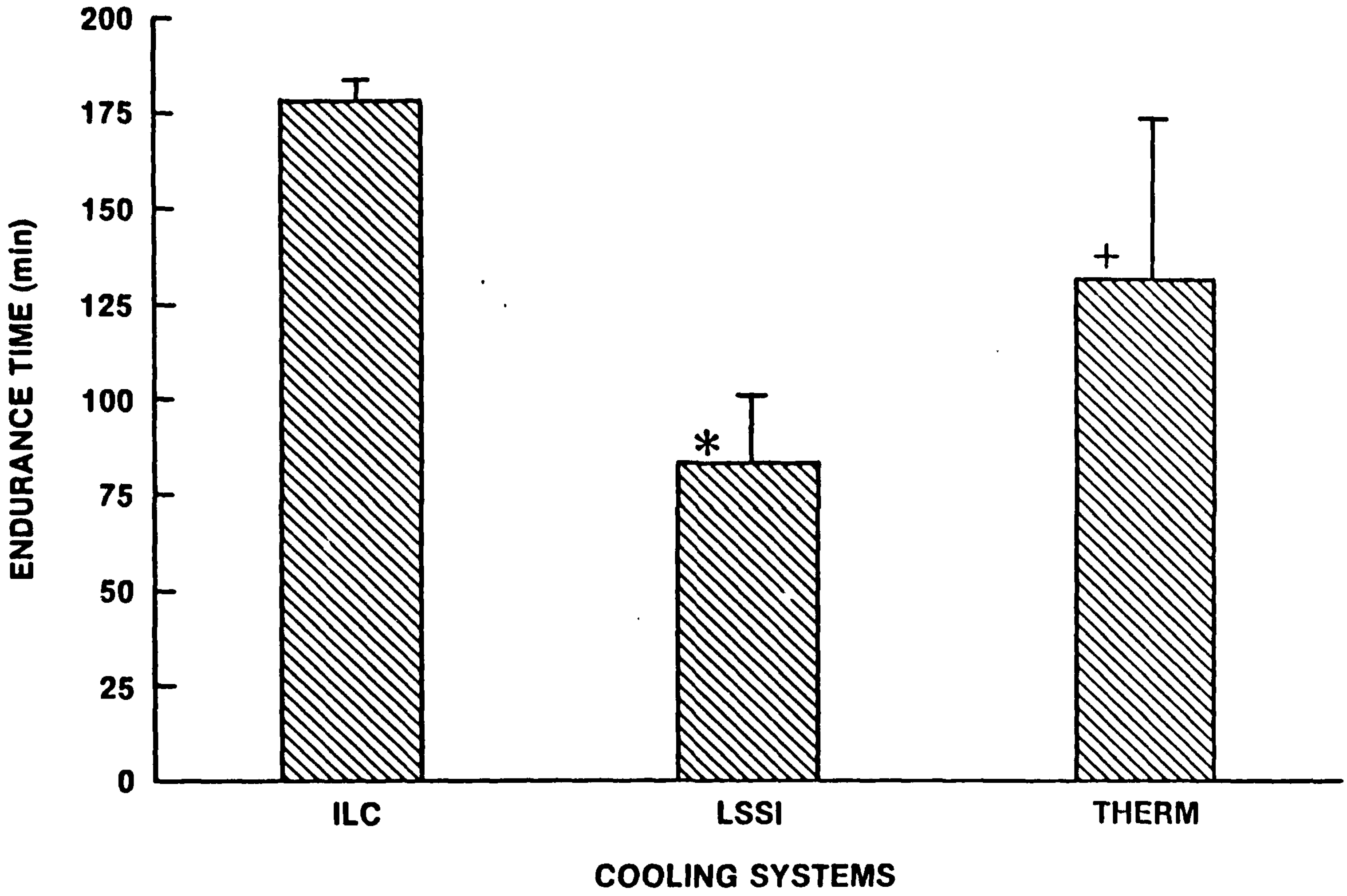
Fig. 2. Endurance time ($\bar{X}$, S.D.) of subjects exercising at 440 W wearing the three microclimate systems.

Fig. 3. Regression lines of subjects' core temperature change across time while wearing the three microclimate systems and as predicted with no cooling.



*LESS THAN ILC AND LSSI ($p<0.05$)

Figure 1



*LESS THAN ILC AND THERM ($p<0.05$)
+LESS THAN ILC

Figure 2

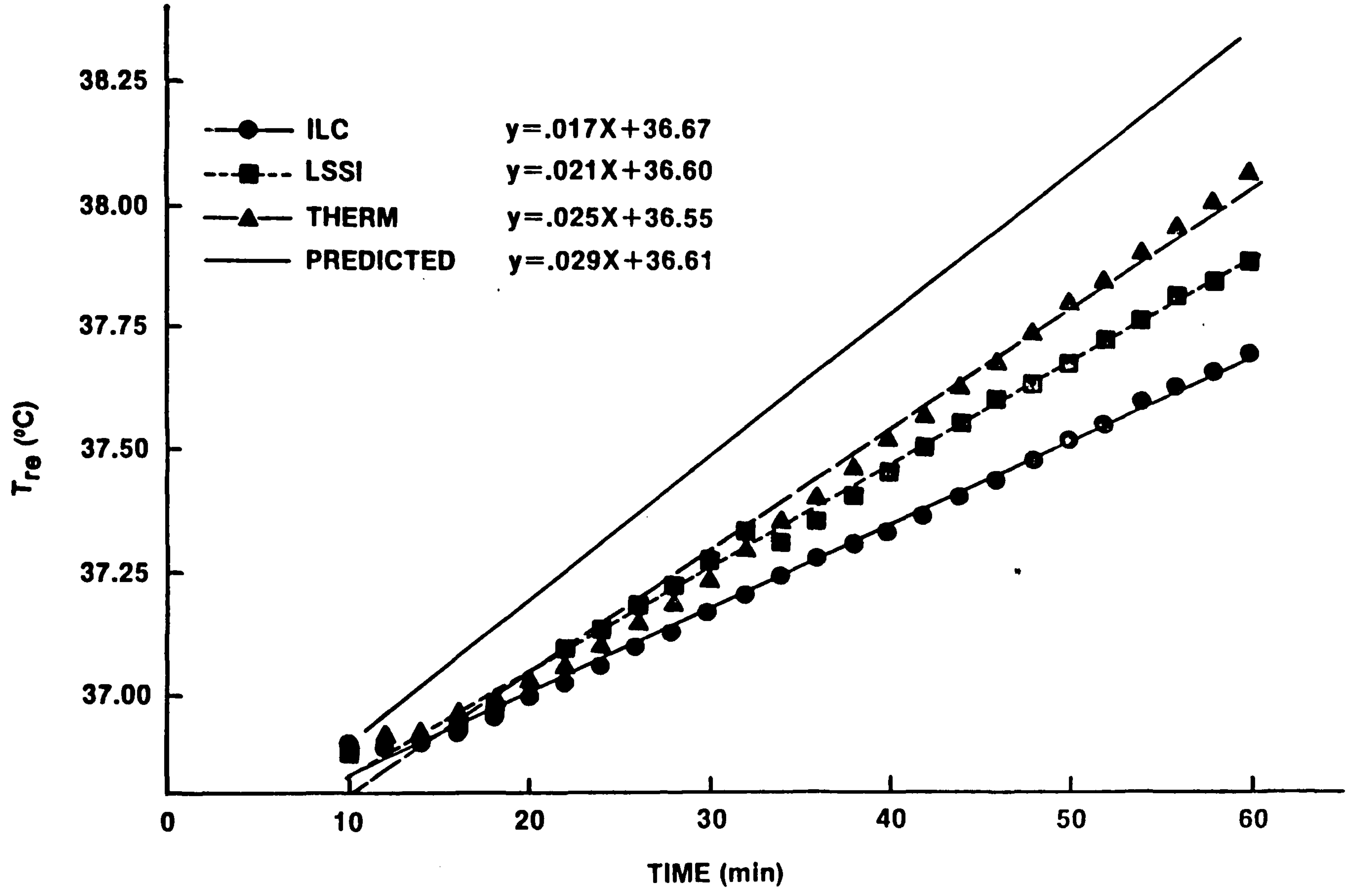

ILC y=.017X+36.67
LSSI y=.021X+36.60
THERM y=.025X+36.55
PREDICTED y=.029X+36.61
38.25
38.00
37.75
37.50
37.25
37.00
T_{re} (°C)
0
10
20
30
40
50
60
TIME (min)

Figure 3